IV&V Program

FSW 2016

Assurance of fault management

Risk-significant adverse condition awareness

Rhonda Fitz, NASA IV&V Program

December 13, 2016

Background

- **Approaches to FM** vary even among similar mission types
  - Deep Space Robotic, Human Spaceflight, Earth Orbiters, Launch Vehicles, Ground Systems
  - Large variance in approach, design, and terminology
- As mission complexity increases, so does **FM complexity**
  - FM may be handled on a subsystem basis on these large, complex missions under the flight software umbrella
  - FM system documentation is often relegated to various subdomain requirements and design artifacts
  - Architectural analysis enables FM capability assessment
- How can we improve **software assurance strategies** given the current visibility into these increasingly complex architectures?

FM Architectures SW Assurance Research Program (SARP) Initiative

IV&V Program

Challenges in Assurance of FM

Increasing FM complexity goes beyond traditional fault protection with the goal of not only averting catastrophe, but also maintaining capability

FM systems, many times architected as reactive components embedded within the overall software system, must be validated against higher-level system capability requirements

Off-nominal conditions are challenging to identify comprehensively, understand completely, and ascertain the optimal response to mitigate risk

Existing software development and assurance practices applied to FM systems need improvement to provide a high level of assurance

IV&V Program

FM Architectures Initiative

Description/Goals

- Analyze FM architectures from a varied set of NASA space missions to develop or expand upon the current FM architecture classification and its terminology
- Investigate IV&V methods and assurance strategies used on FM systems and their possible strengths and weaknesses
- Assess the visibility of FM architectures for a robust software assurance strategy

Products

- FM Architectures, with associated assessments of attributes and associated complexity, visibility
- IV&V Assurance Objectives and Analysis Techniques
- Final report

Value to NASA

- Technical Reference (TR) matrix of the high-level characteristics of select FM architectures and the IV&V methods used on them
- TR on the low-level features of FM systems specific to mission domain and/or developer
- Updates to the Architectures and V&V sections of the NASA FM Handbook

Missions Investigated

Name	Mission Type
Mars Science Laboratory (MSL)	Deep Space Robotic
International Space Station (ISS)	Human Spaceflight
James Webb Space Telescope (JWST)	Deep Space Robotic
Multi-Purpose Crew Vehicle (MPCV)	Human Spaceflight
Joint Polar Satellite System (JPSS)	Earth Orbiter
Magnetospheric Multiscale (MMS)	Earth Orbiter
Geostationary Operational Environmental Satellite R-Series (GOES-R)	Earth Orbiter
Solar Probe Plus (SPP)	Deep Space Robotic
Space Launch System (SLS)	Launch Vehicle

Early Goals Met, Exceeded

- Analyzed **FM architectures** from a small but varied set of current and former space missions to develop or expand upon the current FM architecture classification and its terminology
  - Consequence of various developers/domains is a broad range of FM architectures and styles
  - NASA FM Handbook should be regarded as a source of reference for common terminology
- Investigated IV&V methods and **assurance strategies** used on FM systems and their possible strengths and weaknesses
  - Resulting in TR that provides valuable insight to future software assurance and IV&V efforts
- Assessed the **visibility** of FM architectures for a robust software assurance strategy
  - Artifacts and insight into FM system provided by projects vary
- Determined benefits and limitations in the application of current software assurance methods and **IV&V techniques** across the lifecycle
  - Which methods work? Which don't? Have methods been developed that are not documented and should be more widely used?
  - Captured recommended practices and pitfalls for updates or additions to FM Handbook
- Disseminated **results** via conference presentation and paper, final report, and input to the NASA FM Handbook/Community of Practice
  - Sharing results was the most crucial goal, in order to expand the discussion and formulate future direction for the FM community

Refined Improvement Goals

- Improve and expand upon the current analysis of NASA mission FM with a **Technical Reference Suite** for more comprehensive coverage of architecture, visibility, and assurance strategies
  - Analyze additional FM **architectures**, specifically from a Launch Vehicle space mission to expand upon the current FM architecture classification and its terminology
  - Further investigate SA and IV&V methods and **assurance strategies** used on FM systems to identify benefits and limitations in their application across the lifecycle
  - Learn more about the **visibility** of FM architectures within a nontraditional development environment, particularly within an Agile framework, using a model-based methodology
- Develop and refine the prototype **Adverse Condition Database** for access to IV&V project fault, failure, and hazard data for more rigorous assurance and risk reduction with Q3 analysis
- Disseminate results with FM SA **Knowledge Exchange** via conference presentations and papers, roundtables, and reports

IV&V Program

FM Architectures Encore Initiative

Description/Goals

- Improve and expand upon the current analysis of NASA mission FM in a **Technical Reference suite** for more comprehensive coverage of architecture, visibility, and assurance strategies
- Develop and refine the prototype **Adverse Condition Database** for access to IV&V project fault, failure, and hazard data for more rigorous assurance and risk reduction with Q3 analysis
- Socialize products and findings with FM **Software Assurance Knowledge Exchange**

Products

- FM Architecture Matrix TR, FM Visibility Matrix TR, and dynamic FM Assurance Strategy TR with supporting IV&V methods employed across the development lifecycle
- Repository of NASA mission adverse conditions and associated project metadata
- Technical presentations, conference papers, and informal learning opportunities

Value to NASA

- Promoting FM knowledge for IV&V Program, SARP, and NASA Engineering Network
- Improved assurance from the provision of more comprehensive data
- More rigorous Q3 analysis from identification of off-nominal scenarios
- Increased efficiency of analyst workflow and broader test coverage
- Greater focus on FM and project areas of vulnerability or high risk

Research Thrusts

- **TR products** will be improved and expanded upon for more comprehensive coverage of NASA mission types and non-traditional development approaches
  - Investigate ways to integrate FY16 findings and products into SA and IV&V methods
  - Continue to develop a quick reference guide to improve TR usability for SA analysts across Agency
  - Capture challenges of Launch Vehicles, Agile development, and model-based FM

IV&V Program

TR Suite Screenshots

Pages / ... / FM SARP Initiative

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FM Architectures Technical Reference

Created by Gerek Whitman, last modified on Sep 01, 2016

The TR suite generated by the SARP FMA Initiative consists of three distinct segments.

The Architecture Matrix

The Architecture Matrix is the result of a survey of nine IV&V projects, regarding the structural and functional features of their FM architectures. It is summarized by mission domain: Earth Orbiter, Deep Space Robotic, Human Spaceflight, and Launch Vehicles. The Architecture Matrix is accompanied with diagrams detailing the common structural and functional architecture types we have found in our investigations.

The Assurance Strategy Reference

The Assurance Strategy Reference Table is a collection of assurance objectives and conclusions related to FM from projects across IV&V in various lifecycle phases. It is intended for use as a reference guide of dos (and, in some cases, do-nots) for IV&V and other assurance projects planning and designing an assurance regimen of their FM systems.

The Visibility Matrix

The Visibility Matrix is an aggregation of observations, from research results and SMEs, of some of the typical challenges IV&V analysts face when trying to gain insight into the FM system and its architecture. These observations are associated with development artifacts (some specific, some more notional), and examples are provided of methods or strategies used by projects in the past to overcome visibility challenges.

IV&V Program

TR Suite Screenshots

Pages / ... / FM SARP Initiative

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FM Architectures Technical Reference

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The TR suite generated by the SARP FMA Initiative consists of three distinct segments.

The Architecture Matrix

The Architecture Matrix is the
Space Robotic, Human Spac
investigations.

The Assurance Strategy

The Assurance Strategy Refe
guide of dos (and, in some ca

The Visibility Matrix

The Visibility Matrix is an agg
architecture. These observat
overcome visibility challenges

Pages / ... / FM Architectures Technical Reference

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FM Architecture Matrix

Created by Gerek Whitman, last modified on Sep 01, 2016

Return to FM Technical Reference Main Page

General Findings

The Architecture Matrix was generated from survey responses gathered from FM SMEs on nine IV&V projects that fall into four broad mission domains. Results were aggregated on these domains to form generalizations on the trends seen in the architecture data during collection.

Earth Orbiter Missions	Deep Space Missions	Human Spaceflight Missions	Launch Vehicle Missions
• GOES-R • JPSS • MMS	• MSL • JWST • SPP	• ISS • MPCV	• SLS

The full architecture matrix is presented at the bottom of the page.

IV&V Program

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TR suite has been improved and expanded for more comprehensive coverage and ease of sharing information

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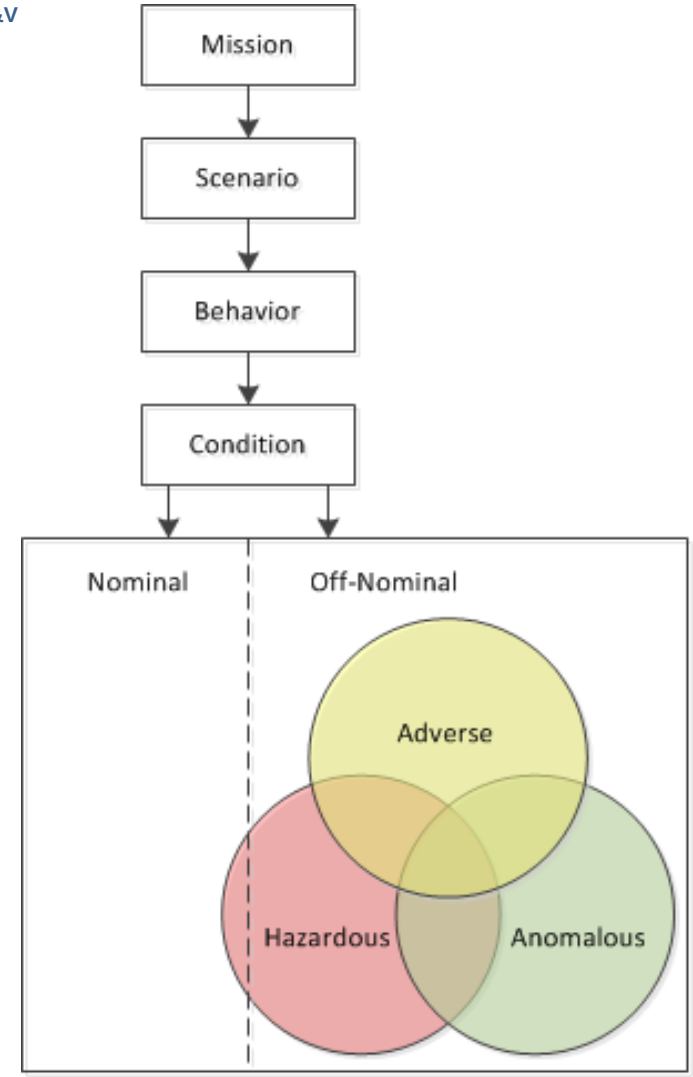
  - Inve[illegible]&V methods
  - Continue to develop a quick reference guide to improve TR usability for SA analysts across Agency
  - Capture challenges of Launch Vehicles, Agile development, and model-based FM
- The **Adverse Condition Database** prototype will be refined and productized for insight into off-nominal mission capabilities with focus on analyst usability
  - Populate AC Database with additional project data from IV&V and SSO projects
  - Align with TRs enabling behavioral and hazard connections
  - Continue to develop more efficient user interface for typical SA or IV&V analyst workflow scenario, based on user stories
  - Develop AC Database user guide

TR suite has been improved and expanded for more comprehensive coverage and ease of sharing information

Adverse Conditions



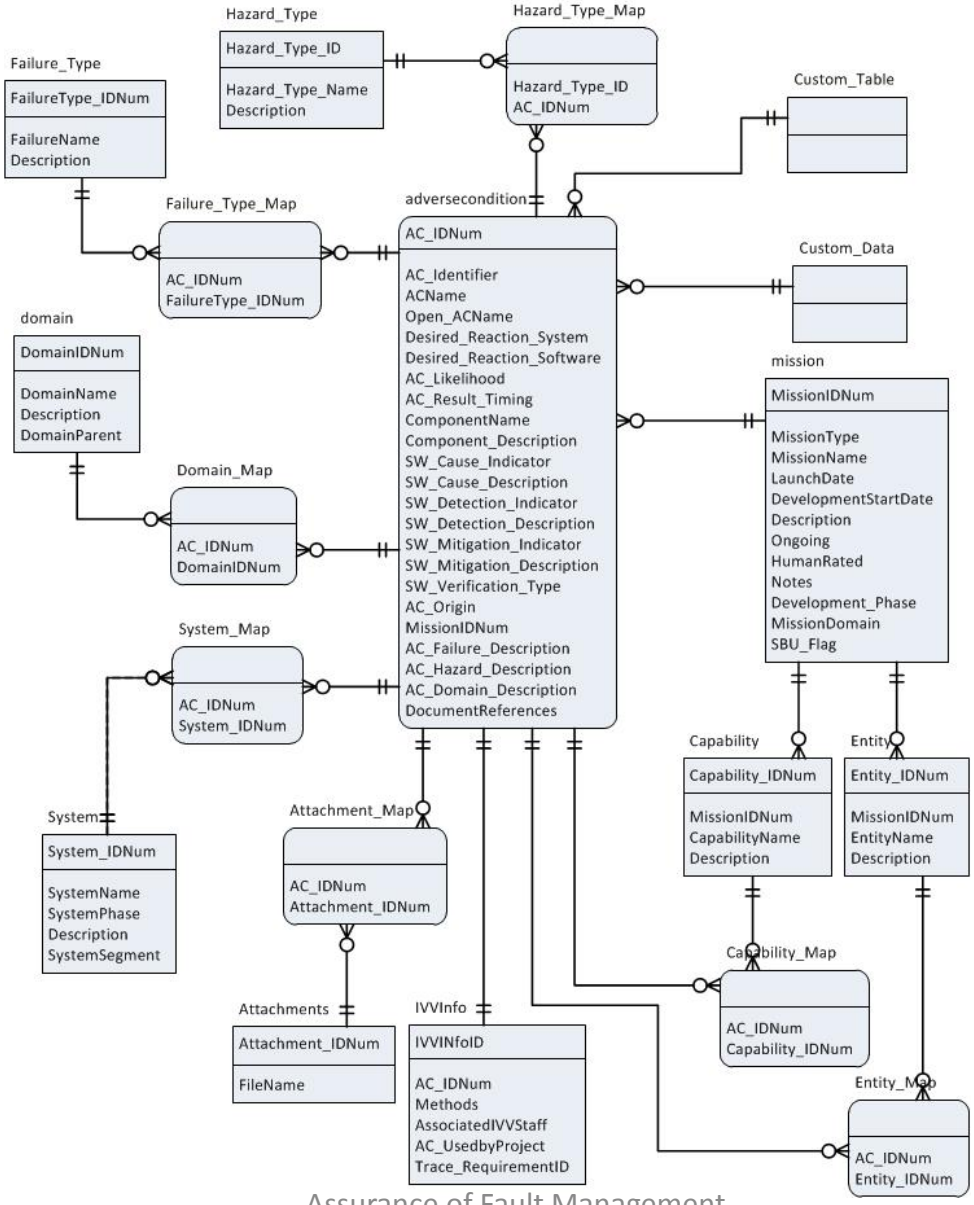
- Examining Q2 and Q3 are major challenges of FM software
- **Adverse Condition**: A subset of an off-nominal state that prevents a return to nominal operations and compromises mission success unless an effective response to the causal fault is employed
- How a system is **architected** to handle faults and adverse conditions is crucial for the satisfaction of functional and performance requirements for mission success

IV&V Program

User Story Workshop

- Workshop focus was to better understand how the IV&V Program could most effectively utilize meaningful **Adverse Condition data** to enhance the software assurance provided
- **Q3 analysis**, "Will the system's software respond as expected under adverse conditions?" brings high value to projects from an independent perspective, focusing on areas of high risk, and assessing the projects' attention to off-nominal scenarios. As part of the SARP FMAE, an Adverse Condition Database is under development to augment the value of SA provided
- With this innovation, we had the following basic goals:
  - Create a database that centralizes a compilation of adverse conditions and related data from IV&V projects
  - Architect the fields such that there may be sharing of data between IV&V projects for more rigorous analysis
- This user story workshop was held to take theories of how the Program could use more rigorous Adverse Condition data and formulate these into "user stories" to inform the development process. Input was requested from all stakeholders and user groups that recognize that our Program will benefit from increased attention to Q3 and the rigorous identification of potential Adverse Conditions, related mitigations, and verifications of such
- As a <user type>, I want to <meet this goal>, so that <some value is created>

Entity-Relationship Diagram



AC Database Screenshots

IV&V Program

Search Form

Select Mission: MPCV [Clear]

Record Count: 12

Select Domain: Electrical Power [Clear]
Select Failure Type: [Clear]
Select Hazard Type: [Clear]
Select System: MPCV Crew Module [Clear]

Show as Datasheet | Add/Edit Mission | Import Data | Add a New AC | Close Database

AC Identifier	AC Name	Open AC Name	Domain Name	Failure Type	Hazard Type	System Name	ComponentName
MPCV-1012	CAUS6: A software-based control error could result in a loss of command and control capability to		Electrical Power		Loss of Command / Control Capability	MPCV Crew Module; MPCV Service Module	CM: Electrical Pov System, SM: Elect Power Subsyster
MPCV-1013	CAUS4: Software Based Control Errors - Software errors could result in premature or inadvertent		Spacecraft Structures and Mechanisms; Electrical Power		Vehicle Structural Damage	MPCV Crew Module; MPCV Service Module	CM: Electrical Pov System, SM: Stru SM: Mechanisms
MPCV-1015	CAUS6: Software Based Control Error 1) Failure of Timeline Management software to properly		Spacecraft Structures and Mechanisms; Pyrotechnics; Wiring; Avionics /		Degraded Vehicle Performance; Premature / Inadvertent Pyrotechnic	MPCV Crew Module; MPCV Service Module	CM: Avionics, CM Electrical Power S CM: Guidance, Na
MPCV-1017	CAUS17: Software Based Control Errors - A failure occurring within EPS controlling/ monitoring		Electrical Power		Loss of Crew; Loss of Power to Safety Critical Functions	MPCV Crew Module; MPCV Service Module	CM: Electrical Pov System, SM: Elect Power Subsyster
MPCV-1018	CAUS11: Software-based Control Errors - Software-related causes include: (1) The Electrical Power		Electrical Power		Fire / Explosion; Habitat / Suit Depressurization; Hazardous Gas /	MPCV Crew Module	CM: Electrical Pov System
MPCV-1019	CAUS7: Software-Based Control Error - Software commanding errors may cause incorrect control		Avionics / Command and Data Handling; Electrical Power ; Environmental		Hazardous Thermal Conditions	MPCV Crew Module; MPCV Service Module	CM: Avionics, CM Electrical Power S CM: Environment
MPCV-1020	CAUS5: Software-Based Control Error - Improper software commanding of ECLSS components		Avionics / Command and Data Handling; Electrical Power ; Environmental		Habitat / Suit Depressurization; Loss of Command / Control	MPCV Crew Module	CM: Avionics,CM: Electrical Power S CM: Environment
MPCV-1022	CAUS9: Software-Based Control Error - Software errors may cause generation of incorrect commands		Spacecraft Separation; Pyrotechnics; Wiring; Avionics / Command and		Loss of Command / Control Capability; Loss of Vehicle	MPCV Crew Module; MPCV Launch Abort System	CM: Avionics, CM Electrical Power S CM: Guidance, Na
MPCV-1043	the vehicle loses all power		Electrical Power		Loss of Command / Control Capability; Loss of Crew	MPCV Crew Module	CM
MPCV-3869	CAUS4: Software-Based Control Error - Software commanding errors may cause incorrect control		Avionics / Command and Data Handling; Electrical Power ; Environmental		Crew Incapacitation, Illness, or Injury; Loss of Command / Control	MPCV Crew Module	CM: Avionics, CM Electrical Power S CM: Environment
MPCV-3870	CAUS9: Software-Based Control Error - Software commanding errors may cause incorrect control		Avionics / Command and Data Handling; Electrical Power ; Environmental		Crew Incapacitation, Illness, or Injury; Hazardous Gas /	MPCV Crew Module	CM: Avionics, CM Electrical Power S CM: Environment
MPCV-3871	CAUS6: Software-Based Control Error - Software commanding errors may cause incorrect control		Avionics / Command and Data Handling; Electrical Power ; Environmental		Crew Incapacitation, Illness, or Injury; Loss of Crew	MPCV Crew Module	CM: Avionics, CM Electrical Power S CM: Environment

AC Database Screenshots

IV&V Program

AC Detail Form

AC Identifier: MPCV-1012

AC Name: CAUS6: A software-based control error could result in a loss of command and control capability to HDRMs or SADA necessary for solar array deployment. This would result in the inability to deploy the solar arrays in and inadequate power generation resulting in

Duplicate AC Record | Add a New AC | Close and Go Back to Search Form

Mission Data

Mission Name: MPCV

Launch Date: 2018-09-01

Development Start Date:

Ongoing: Y

Human Rated: Y

Mission Domain: HEO

Data Marked as SBU: N

Mission Type: Human Spaceflight

Mission Description: The Orion Multi-Purpose Crew Vehicle (MPCV) is a spacecraft intended to carry a crew of four astronauts to destinations at or beyond loe Earth Orbit (LEO). Current under development by NASA for launch on the Space Launch System (SLS).

Mission Notes:

AC Data

AC Likelihood:

Edit AC

AC Origin: HR #: MPCV-FLT-035 Failed / Partial Deployment of

Document References: 1.8 Electrical Power System - Redundant control power is provided to all the cards internal to the Power and Data Unit through the internal power supply (IPS) cards. SLS abort recommendation is received by PDUs. - Power Management (PWM) domain software performs command processing for the power distribution subsystem. 1.3 Vehicle System Management - subset of vehicle functions that

Open AC Name:

AC Domain Description:

Component Name: CM: Electrical Power System, SM: Electrical Power Subsystem

Component Description:

Domain Links

Add/Delete Domain

Domain Name: Electrical Power

Domain Description: Select 'Domain Name' to see Description

Failure Types

Add/Delete Failure

Failure Name:

Failure Description: Select 'Failure Name' to see Description

Hazard Types

Add/Delete Hazard

Hazard Name: Loss of Command / Control Capability

Hazard Description: Select 'Hazard Name' to see Description

System Categorization

Add/Delete System

System Name:

IV&V Program

AC Database Screenshots

Mission Form

Save Record | Cancel Changes | Close and Go Back to Search Form

Add/Edit Mission Data

Mission Name: MPCV

Launch Date: 2018-09-01

Development Start Date:

Ongoing: Y

Human Rated: Y

Mission Domain: HEO

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Data Marked as SBU (Y or N): N

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Mission Notes:

Capabilities:

Capability Name	Description
Abort	Provides abort capabilities while systems are on the pad, during launch and ascent and on-orbit operations
Ascent Environment	Capability to withstand natural and induced environments experienced during ascent mission phases.
Attitude Control	Provide attitude control.
Auxiliary Comm	Auxiliary Voice Communication link capabilities.
Early Mission Termination	Provides early mission return capabilities while systems are performing in-orbit operations.
ECLSS and ECS Services	Maintain habitable atmosphere, partial pressure, humidity, temp control, trace contaminant, hazard detect
EDL and Recovery Environment	Capability to withstand natural and induced environments experienced during applicable recovery phases.
Entry Descent and Landing	Entry, Descent, and Landing Capabilities associated with MPCV and Mission Systems.
Fueling and Conditioning	Includes propellant loading storage and pressurizations capabilities.
Ground Processing	Provide ground operations capabilities for off-line processing, integrated operations, pad and launch opera
Guidance and Navigation	Determine state vector, targeting, and control functions.

Record: 1 of 30 | No Filter | Search

Entities:

Entity Name	Description
BEL	Backup Engage Logic
BFS	Backup Flight Software
CDH	Command & Data Handling
CFSW	Common Flight Software
CMT	Communicate & Track
CORE	Core Flight Software

Record: 1 of 1 | Filtered | Search

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AC Database has been refined and productized for insight into off-nominal mission capabilities

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- **Research findings** and products will be socialized within the SA community to collaborate for the advancement of FM assurance across the Agency
  - Travel to select NASA centers for SA of FM knowledge exchange
  - Consolidate results and document lessons learned and present to SA Working Group

Space Symposium Tech Track

31st Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
Presented on April 13-14, 2015

Fault Management Architectures and the Challenges of Providing Software Assurance

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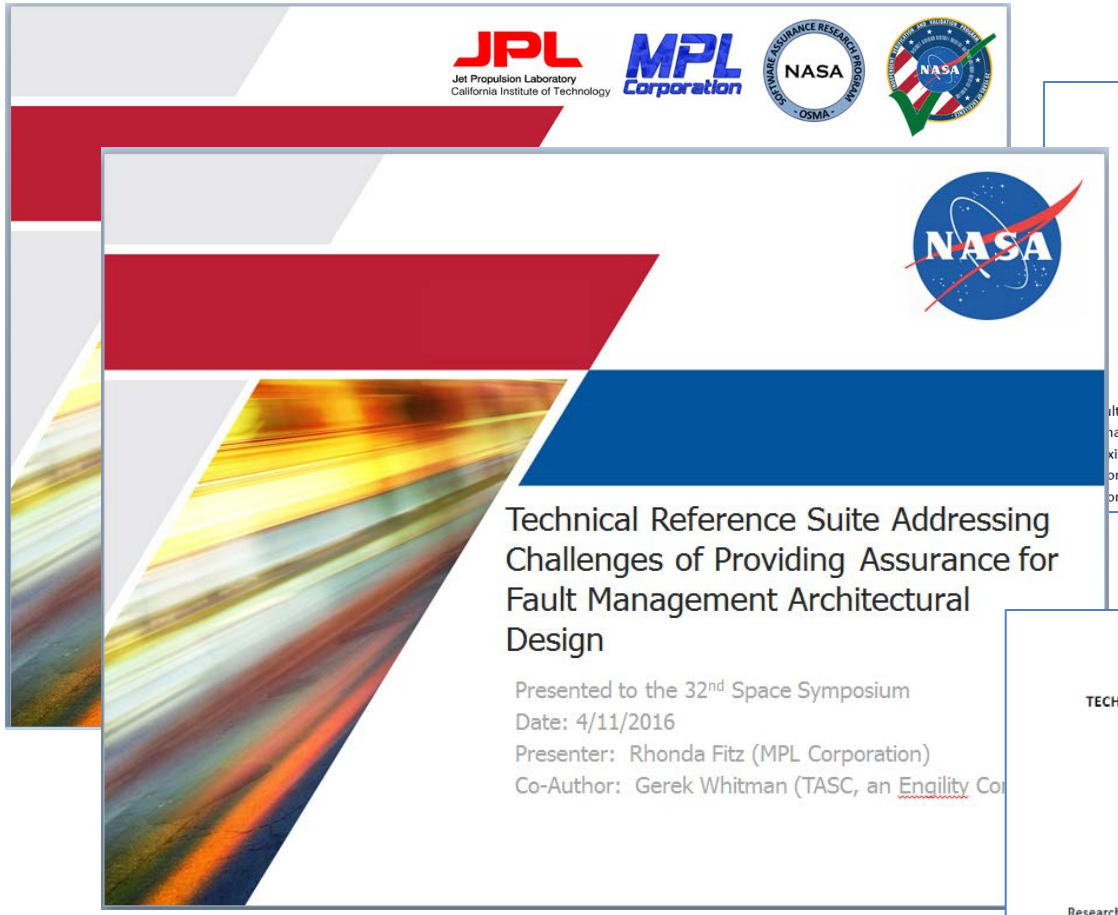
ABSTRACT

Fault Management (FM) is focused on safety, the preservation of assets, and maintaining the desired functionality of the system. How FM is implemented varies among missions. Common to most missions is system complexity due to a need to establish a multi-dimensional structure across hardware, software and spacecraft operations. FM is necessary to identify and respond to system faults, mitigate technical risks and ensure operational continuity. Generally, FM architecture, implementation, and software assurance efforts increase with

IV&V Program

Space Symposium Tech Track



31st Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
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Fault Management Architectures and the Challenges of Providing Software Assurance

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32nd Space Symposium, Technical Track, Colorado Springs, Colorado, United States of America
Presented on April 11-12, 2016

TECHNICAL REFERENCE SUITE ADDRESSING CHALLENGES OF PROVIDING ASSURANCE FOR FAULT MANAGEMENT ARCHITECTURAL DESIGN

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TASC, an Engility Company, gerek.whitman@engilitycorp.com

ABSTRACT
Research into complexities of software systems Fault Management (FM) and how architectural design decisions affect safety, preservation of assets, and maintenance of desired system functionality has coalesced into a technical reference (TR) suite that advances the provision of safety and mission assurance. The NASA Independent Verification and Validation (IV&V) Program, with Software Assurance Research Program support, extracted FM architectures across the IV&V portfolio to evaluate robustness, assess visibility for validation and

IV&V Program

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TR suite has been improved and expanded for more comprehensive coverage and ease of sharing information

AC Database has been refined and productized for insight into off-nominal mission capabilities

Research shared with FM and SA communities

FY16 Advancements

- Finalized updates and migration of **TR suite** onto Confluence
  - Improved and updated the Confluence page for usability and to communicate the TR suite and other project advancements with enhanced HTML reporting feature
  - Launch Vehicle FM researched, summarized with inclusion of SLS data
- Finalized integration of project Adverse Condition data into **AC Database**
  - Fifteen IV&V projects include: GSDO, HEO Integration, ICESat-2, InSight, ISS, JPSS Flight, JPSS Ground, JPSS-2, JWST, Mars 2020, MPCV, OSIRIS-REx, SGSS, SLS, and SPP
  - Improvements made to the AC Database include core functionality (search, enter, edit), architectural changes, user interface changes, and automated import process
  - Capability Based Assurance workflow evolution enabled with additional fields
- Provided numerous outreach opportunities for **knowledge exchange**
  - Paper presented at 32nd Space Symposium, tech discussions, and workshops held
  - Held introductory courses on relational database architecture and management
  - Coordinated summer intern effort for assistance in AC Database development
- Collaborative **deployment** plans have been initiated
  - IV&V Senior staff support and direction for integration within Enterprise Architecture
  - Communication with tool developers for user-focused deployment is in place
  - Follow-on proposal activities have been accepted

Initiative Overview

Description/Goals

- Improve and expand upon the current analysis of NASA mission FM with a **Technical Reference Suite** for more comprehensive coverage of architecture, visibility, and assurance strategies
- Develop and refine the prototype **Adverse Condition Database** for access to IV&V project fault, failure, and hazard data for more rigorous assurance and risk reduction with Q2/Q3 analysis
- Disseminate results with **FM SA Knowledge Exchange** via conference presentations and papers, roundtables, reports, and informal learning opportunities

Value to NASA

- Promoting FM knowledge for SARP, IV&V Program, and NASA Engineering Network
- Improved assurance from the provision of more comprehensive data with specific guidance
- More rigorous IV&V analysis from identification of off-nominal scenarios and cross-project AC data sharing
- Increased efficiency of analyst workflow with focused methods and broader visibility and test coverage
- Greater focus on FM and project areas of vulnerability or high risk in terms of software reliability

FY16 Advancements

- Finalized updates and migration of TR suite onto Confluence with enhanced reporting feature
- Finalized integration of project Adverse Condition data from 15 IV&V projects into the AC Database
- Refined AC data import template, automated import process, improved usability and query timing
- Added functionality for capabilities and entities for Capability Based Assurance workflow evolution
- Collaborative deployment plans initiated

Planned Infusion

- TR suite has been improved and expanded upon for more comprehensive coverage of NASA mission types and non-traditional development approaches
- The AC Database has been refined and productized for insight into off-nominal mission capabilities
- Research findings and products have been and will continue to be socialized within the SA community to collaborate for the advancement of FM assurance across the Agency and the spaceflight community

Added Value

- Products and results are a step toward filling a number of gaps in the FM knowledge domain for SA community and IV&V across the Agency
  - TR suite provides cross-project, cross-agency **FM architecture** and software assurance knowledge sharing with practical application
  - Labor savings realized as analysts capitalize on deeper understanding of FM **Software Assurance strategies**, methods and tools in order to be efficient in providing domain specific FM assurance
  - Recommended techniques reduce risk of lack of **visibility** into FM architecture and boost assurance throughout the project lifecycle

Added Value

- Collaboration and infusion of results will continue as the TR suite and the **AC Database** are deployed, and methods are developed to take advantage of both as dynamic, living resources tailored to improve workflow
  - Improved assurance from the provision of more comprehensive **off-nominal data** with specific project examples available for guidance
  - More rigorous **Q2/Q3 analysis** from identification of off-nominal scenarios through cross-project AC data sharing and identification of relevant relationships
  - Increased efficiency of **analyst workflow** with focused methods and broader visibility and test coverage across the system for management of scope
  - Greater **focus on FM** and project areas of **vulnerability** or high **risk** in terms of software reliability in support of Capability Based Assurance

Additional Information

- FM NASA Engineering Network (NEN)
  - https://nen.nasa.gov/web/faultmanagement
- SW Assurance Research Program products
  - https://nen.nasa.gov/web/sarp

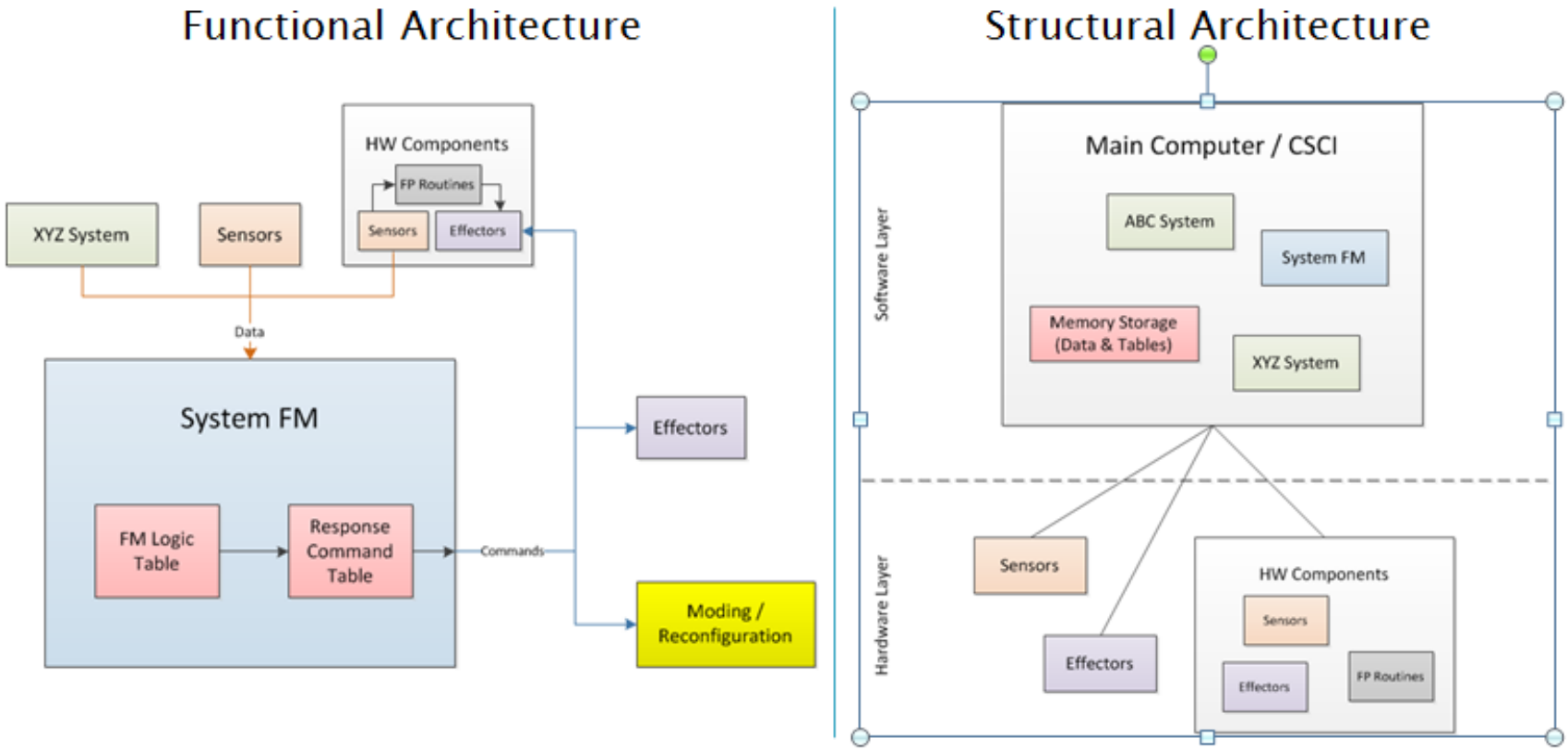
- Contact:
  - Rhonda Fitz (rhonda.s.fitz@nasa.gov)

Backup Slides

Architectural Views

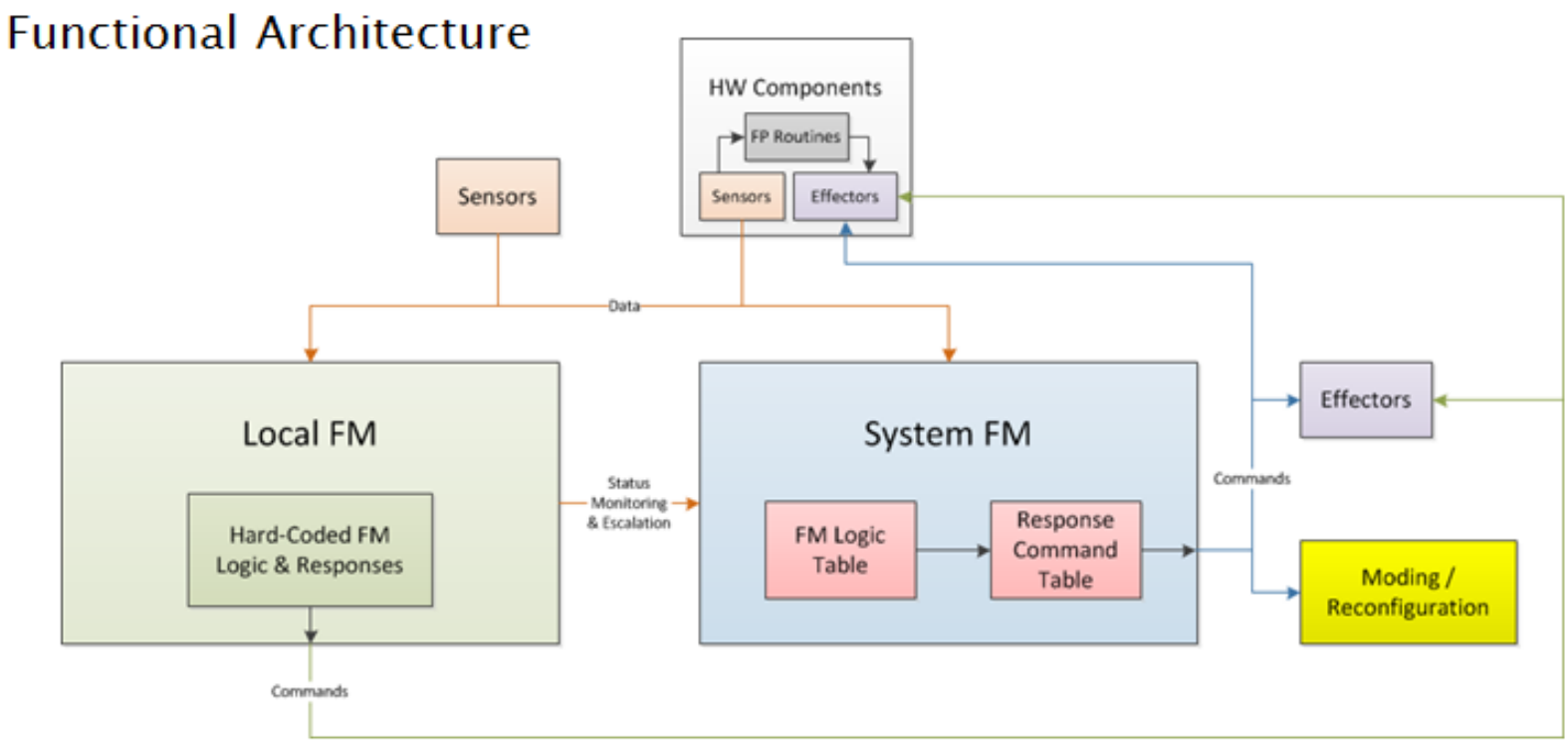
- **Structural/Physical**:
  - How are individual components and entities related, joined, or positioned?
  - What groupings are used to encapsulate individual pieces?
  - What are the interfaces between different parts?
- **Functional**:
  - How does the architecture accomplish a purpose or goal?
  - How does the system get from Point A to Point B?
  - How does data flow through the system?
- **Centralized**:
  - Architectures with only one tier of FM activity at the system level, which has full control over all subsystems
- **Distributed**:
  - Architectures with at least one tier of FM activity that has no master controller directing individual entities
- **Hybrid**:
  - Architectures with multiple tiers of FM activity, where the highest tier is at the system level and can direct lower tiers

Centralized FM Architectures



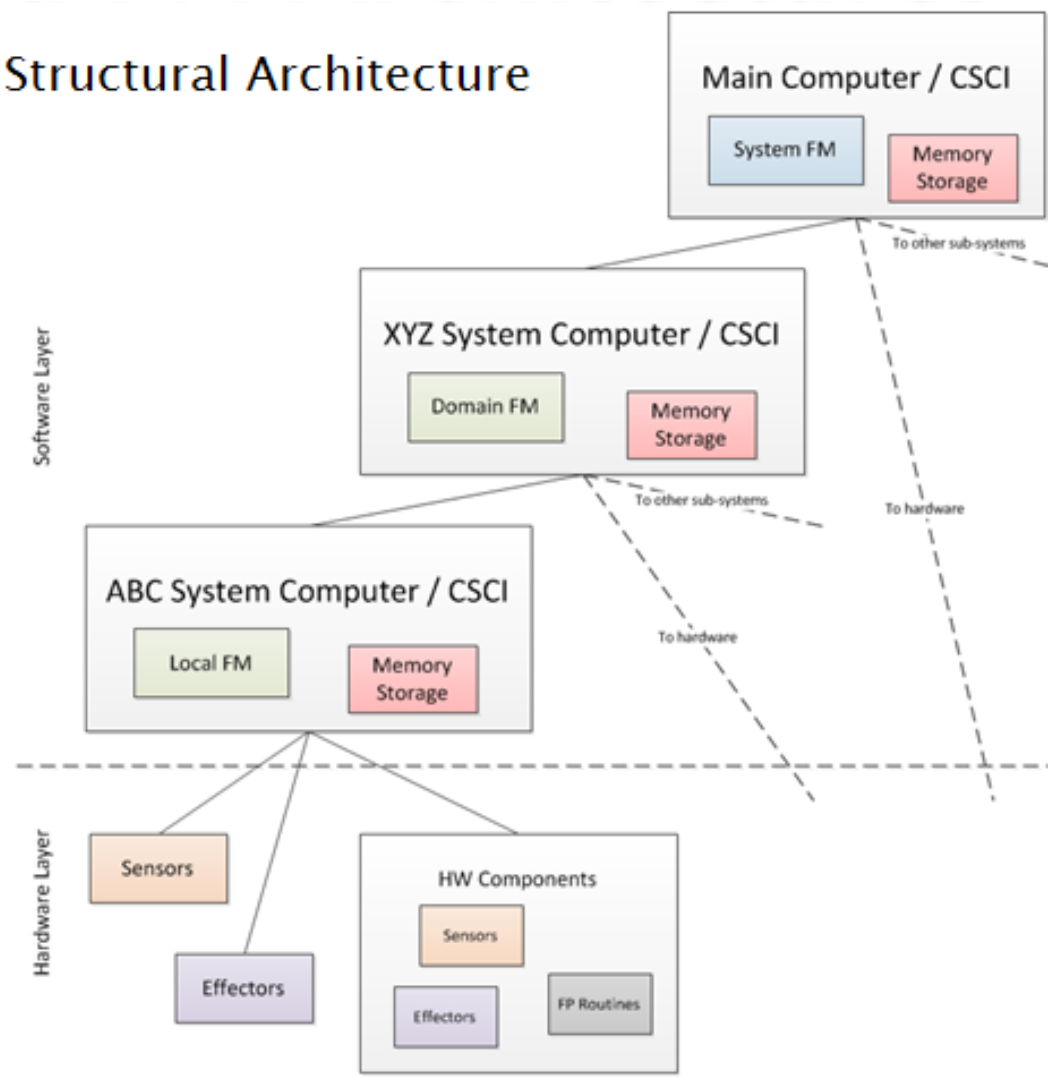
Centralized architectures are common in Earth Orbiters

Hybrid FM Architectures



Human Spaceflight and Deep Space Robotic missions commonly use hybrid architectures

Hybrid FM Architectures



Architecture Findings

- Some trends can be seen along **mission domain**: Earth Orbiter, Deep Space Robotic, Human Spaceflight
- **Table and data-driven** architectures are common, and enable more software re-use of FM engines
- Developers tend toward **re-use** even when architectures may not be intended for a particular mission type
- **Implementation** of FM capabilities typically **lags** behind other implementation, even when it would complement the nominal case
- FM architectures designed early and with intention **reduce risk** by:
  - Enabling more **communication** between development teams, as well as with stakeholders
  - Managing system **complexity**

Visibility Findings

- Availability and quality of artifacts has a large impact on analyst visibility
- Often, artifacts have sufficiently detailed information on FM, but are disorganized and scattered across many documents
  - Mining these documents for FM details may be necessary to develop a system understanding
- Model-based FM development may help to alleviate visibility challenges by imposing centralization of FM architectural design
- Development of a robust and well-maintained TR helps to mitigate visibility challenges as a project progresses